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OF THE

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RESULTS FROM COMPUTER PROGRAM FOR ANALYZING SCATTERED LIGHT SUPPRESSION SYSTEMS

FOR LARGE SPACE TELESCOPE

W. G. Tifft

B. B. Fannin

May 3, 1974

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RESULTS FROM COMPUTER PROGRAM FOR ANALYZING SCATTERED LIGHT SUPPRESSION SYSTEMS FOR LARGE SPACE TELESCOPE

NASA Contract NAS 8-27804

Submitted by:

W. G. Tifft
Principal Investigator

B. B. Fannin
Project Engineer

SPACE ASTRONOMY GROUP

of the

STEWARD OBSERVATORY

UNIVERSITY OF ARIZONA

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INTRODUCTION

This report covers the results to date of the work performed by University of Arizona personnel on Tasks III & IV of Contract NAS 8-27804, Stray Light Suppression Study for the Large Space Telescope. Task III is the development of mathematical models and computer programs to assist in the design and analysis of light suppression systems, and Task IV is to suggest practical design(s) for a light suppression system for the LST based on the results of Task III.

A computer program has been developed which has the ability to analyze the performance of most light suppression systems so as to predict the amount of scattered light which will reach the image plane for various conditions of unwanted light input from the sun, earth, or moon. This program has been used to analyze three different configurations of the LST-- the Phase A LST with a truncated sunshield, an LST with an extended cylindrical sunshield, and an LST with a conical sunshield which is tilted "upwards" (towards the sun). Several variations of each design have been examined, so that a total of ten computer analyses have been made.

The computer program gives the user detailed information as to the paths taken by the unwanted stray light to reach the image plane, and pinpoints those portions of the light suppression system which contribute most of the stray light, so that areas requiring improvements are evident. Based on the results of the program, certain design guide lines have been formulated as being desirable for any light suppression system selected for the LST. One design which meets these requirements (the tilted sunshade) is described in some detail.

This report does not give detailed information as to the structure or operational techniques for the computer program; this information will be contained in a separate report, "User's Manual for Computer Program for Stray Light Suppression System Analysis", which will be issued shortly.

I. HISTORY OF USE OF COMPUTER PROGRAMS FOR BAFFLE SYSTEM ANALYSIS

There have been a number of computer programs intended to assist in the design or analysis of baffle systems for reducing scattered light. At least five programs have been developed which utilize the Monte Carlo technique for predicting baffle system performance, including (1) The GUERAP program developed for the Air Force by Minneapolis-Honeywell (Roger Heinisch), (2) A Soviet Union program developed by B. M. Golubitskiy (see Soviet Journal of Optics Technology, May, 1970), (3) A program used to analyze the TO-1 experiment, ESRO satelites, and the IUE,developed by A. Boksenberg of University College, London, (4) An Aerojet Electro Systems program (R. C. Coda), and (5) A Bellcom program (P. L. Whitlock). The Monte Carlo technique uses probability functions and statistics. A number of photons of unwanted light enter the front of the telescope tube; each photon is analyzed to determine where it will probably go, based on the scattering probability functions of the telescope tube, baffles, optical surfaces, etc. Some of the photons will end up at the image plane as unwanted scattered light. If enough photons are considered, and if the scattering functions of the surfaces are accurately known, the amount of scattered light reaching the image plane can be predicted with a high degree of certainty. However, for complicated systems, the Monte Carlo approach has two serious short comings: (1) For even a moderate degree of accuracy, a large number of photons must be considered, resulting in large amounts of computer time; and (2) There is little intutitive feel as to what changes should be made to a baffle system in order to improve the performance. A given system may be tested, but any changes to the system constitutes a new system. An iterative approach can be used to reach an optimum design, but the cost is likely to be prohibitive.

There is another computer program, GUERAP II, developed by Perkin-Elmer, which utilizes a ray trace approach for analyzing baffle systems. The U of A has not as yet obtained a copy of this program, but it is our understanding that it is quite complicated and requires a large amount of computer time and core space.

II. UNIVERSITY OF ARIZONA COMPUTER PROGRAM FOR ANALYSIS OF BAFFLE SYSTEMS

A different approach has been used by the University of Arizona; the analysis starts at the image plane and progresses from there through the optical system to the front end of the telescope. The evaluation utilizes the $y,\bar{y}$ diagram, which is a powerful geometrical tool that enhances appreciation of all the first order or paraxial properties of an optical system. It is relatively easy to use and in one diagram contains all the information needed in this analysis. The $y,\bar{y}$ diagram is obtained from a ray trace of the marginal and chief rays through the system. All further information such as conjucate image positions, heights, and areas are extracted from the diagram. One layout of the LST yields the following information:

(1) The optical system as seen from image space is laid out. It gives the position of all the baffles and optical surfaces as seen from any point in the image plane and all elements are correctly scaled. From this image layout the sections of the baffles that are seen can be determined.

(2) These sections are then easily reimaged back into real space using the same $y, \bar{y}$ diagram.

(3) The angle of reflection, in real space, at which the baffle is seen by the optics can be calculated as a function along the baffle. In

this way angular scattering characteristics of the baffles can be optimized.

(4) The baffle areas as seen from image space are easily projected into any desired plane (such as the exit pupil) and the area determined. Once the radiance of the baffles, image plane, and optical surfaces is determined, the total irradiance in the image plane can be calculated. These values can be quickly determined for any changes in system configuration, source position, surface reflection/scattering characteristics, etc.

Figure 1 shows a simple version of the LST (primary and secondary conical baffles only, no ring baffles or light traps) as viewed from the image plane. Numbers without primes indicate surfaces seen in real space, numbers with single primes indicates surfaces seen through a single reflection, and double primes two reflections. Figure 1 (as was Figure 2) was drawn by the computer, with cross-hatching added for clarity. The image plane directly sees the inside of the primary baffle (not cross hatched) and part of the secondary baffle.

Figure 2 is a plot of the areas seen by the image plane. The scale is blown-up to show more detail so that point 3, the near end of the primary baffle, is several inches off the paper. The cross-hatched area represents the part of the secondary baffle, surface 5 to 6, that is directly seen by the image plane. Note that point 5 itself is not seen, but some point between 5 and 6 as determined by the obscuration introduced by the primary baffle 3 to 4. The areas on the plot are directly related to the areas seen by the image plane, so the importance of each surface is established. A separate calculation obtains the angle at which each surface is viewed.

This basic procedure is repeated back through the telescope; what each area "sees" is determined in turn until the mouth of the telescope (and

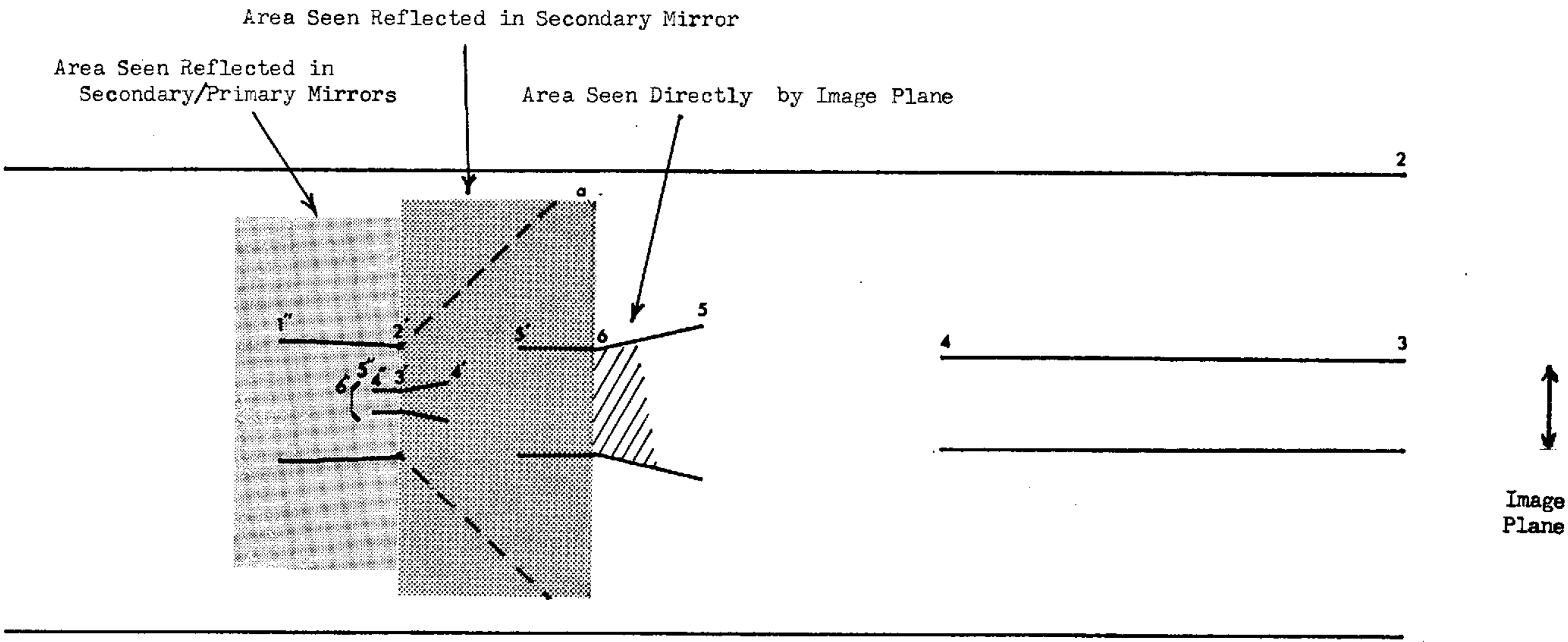


Figure 1 : SIMPLE TELESCOPE AS VIEWED FROM IMAGE PLANE

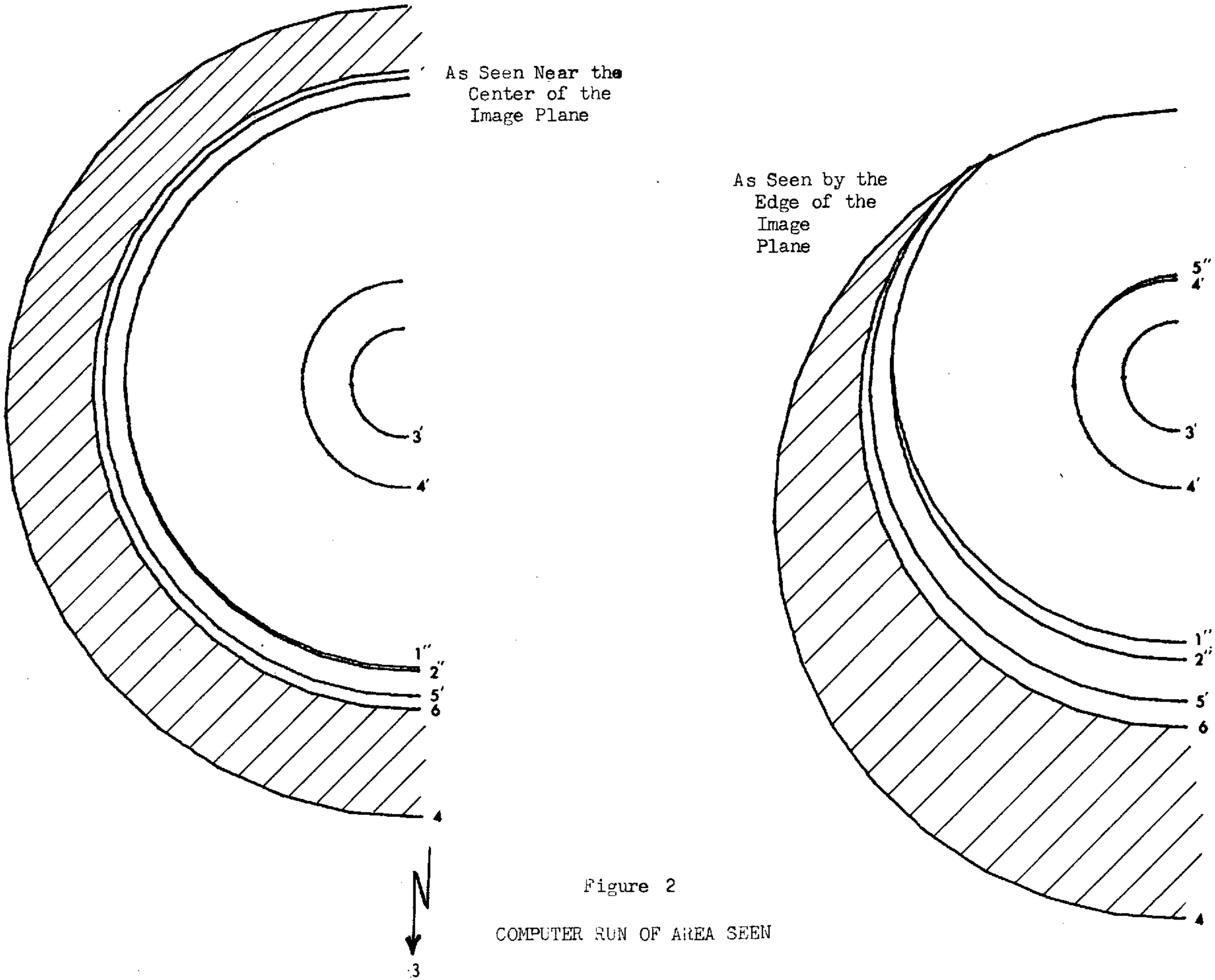


Figure 2

COMPUTER RUN OF AREA SEEN

sources of unwanted light) is reached. By the addition of the proper scattering coefficients for each surface, the amount of scattered light reaching the image plane may be calculated.

A. Program Description

There are six basic programs which make up the complete U of A computer analysis program for the study of light suppression in the LST. Although any one program may be run independently of the others, it is intended that programs two through six be in one job train, each creating files for the succeeding programs. Program one is the only one that does not create nor depend on any external files. Not included in the above six are three utility programs to save and merge files for later use. These are not necessary, but have proved to be useful. Also, there is a sterro program to help visually analyze the different systems.

1. Objects Seen From the Image Plane

Program one looks out from the image plane and determines those objects that are seen from the image plane. These are the only areas that can directly scatter light to the image plane. Program one indicates those surfaces and the angle at which they are seen in real space. (Figures 1 and 2 were plotted by Program one.) Any surface seen is divided into five segments; the position and angle of each segment is printed out. This initial program helps to quickly see any major flaws in the system design, and will reduce the amount of calculations needed to be executed by the succeeding programs.

2. Real and Imaged Space Calculated and Plotted

Program two is similar to Program one; it uses the same data deck input and also lays out the imaged spaces as seen from the image plane. In addition, it lays out the image spaces as seen from object space; that is, "Looking into the primary, what do the reflected spaces look like?" This is necessary to determine where the scattered light can scatter. It also does this for the space between the primary and secondary which turns out to be a partial combination of the other two cases. Although this may appear to be redundant in the case of the LST, it will not be so for other systems. The output is plotted for each space so that one may see how and where real space objects are imaged or reimaged. The printout gives the numerical data of the imaged objects. This includes distances, heights, y, $\bar{y}$, and any objects whose image passes through infinity. It creates an important file that is necessary for the succeeding programs; this file is catalogued as Basica.

3. Geometrical Power Transfer

Program three attaches most of the information it needs from Basica. It will take any object from program two and treat it as a source of radiation to any other object, including the imaged objects. The data input at this stage can be as simple as two numbers--source object number and collector object number. This program creates five important files: (1) the geometrical percentage of power transferred from each segment of the sources to each segment of the collectors, (2) the angle out of the source, (3) the angle into the collector, (4) a mass of information about the source and collector is put in file Passon, and (5) more information is added to Basica.

4. Obscuration (Shadow) Calculations

Program four attaches Basica and Passon and from these calculates the percent of power that is obscured by other objects in the system, including the apertures, and the imaged objects and apertures. The program input is the list of those objects causing the obscuration. The output includes a binary map of the collector surface and a table of percentage of surface seen. Also, one more massive file is created containing the percentage information. This file is merged with the percentage of energy transferred from program three.

5. Power Input to Sunshield (Loading)

Program 5 is the program which "loads" the sunshield with unwanted light, i.e., from the sun or earth. The term "sunshield" is used even though there may be no part of the telescope structure designed specifically to prevent the sun from entering the telescope tube; the term refers to the forward portion of the telescope structure which, when illuminated by a light source, will reflect or scatter light into the main telescope tube.

This program considers the position, intensity, and extent (when the light source is an extended object, such as the bright earth) of the source of unwanted light; this is combined with the geometry of the telescope structure to determine the total light level (in watts) which will then be reflected/scattered further into the telescope tube and, after attenuation, reach the image plane as unwanted scattered light. The information from this program is stored on Tape 2. This program is so dependent on the geometry of the telescope being analyzed that a separate Program 5 is written for each configuration of LST.

6. Calculation of Scattered Light

Program six is the driver program for determining the scattered light levels throughout the system. All scattered light reaching the image plane is printed out so it can be determined which surfaces are the major contributors and how much power is received from each section. It requires: (1) the merged file from program three and program four, (2) file angle in, (3) file angle out, (4) Basica, and (5) the input file. The input to this part of the program is large. It needs to know the light paths that are to be considered for this level of scattering; this advoids unnecessary and expensive calculations of scattered energy to surfaces that are not seen from the image plane and do not scatter to surfaces that are seen. It also needs the vane position, angle of the vane, reflectance of the coating, etc.

The total output map of all the energy on each segment is put on tape by a utility program for later analysis.

B. How Surfaces are Handled

The preceeding sections referred to "objects seen by the image plane", and "power transferred from one object to another", and "one object obscured by another". This section will attempt to clarify what is meant by the term object, and how "objects" are handled.

1. The Definition of "Object"

Consider Figure 3 below, which shows an LST in the presence of sunlight. The sun illuminates one object (the sunshield), a portion of this light is scattered to another object (the main telescope tube wall); from here it is rescattered to another object (the secondary mirror conical baffle), from which, since the inner surface of the secondary conical baffle is "seen" by the image plane, scattered light arrives at the image plane. We have illustrated one of the paths by which stray light may reach the image plane. However, note that <u>all</u> of the sunshield is not illuminated, and that it does not scatter to <u>all</u> of the telescope wall, etc. Therefore it is not practical to have calculations which compute the amount of light transferred from (the sunshield)-to-(the tube wall)-to-(the conical baffle)-to-(the image plane) by any process which considers each of these major portions of the telescope as an entity to itself.

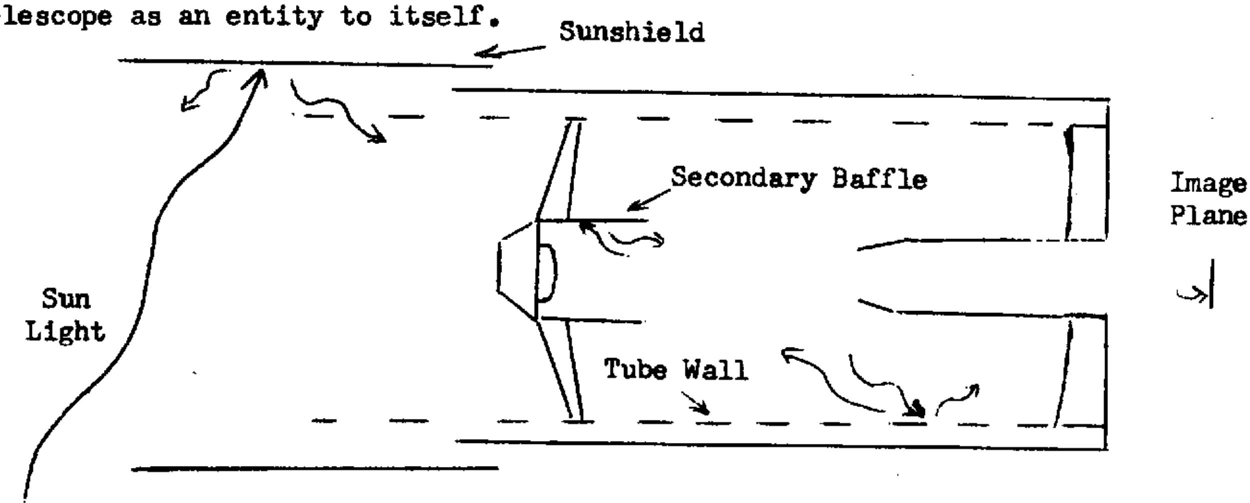


Figure 3: LST in Sunlight

For the purpose of evaluation by the U of A computer program, the LST was divided into eleven major surfaces which can contribute to the scattering of unwanted light, as is listed in Table I. Note that a structural member of the LST may have more than one surface listed, such as the primary mirror conical shield which has both the inside surface and the outside surface considered. Each surface is further divided by segment lines and annular rings into a number of smaller areas, as is shown in Figure 4 (Note: Not all of the surfaces are illustrated in the figure.) Each surface is divided into five segments in order to obtain rotational symmetry (this reduces the number of power transfer calculations almost in half); the number of annular rings varies with the size and importance of the surface. Table I lists the number of rings for each surface, with the resulting total number of incremental areas.

Each incremental area is treated as a separate "object" which can receive or transmit radiation to or from any of the other areas that it can "see", either directly or reflected in the optical surfaces.

2. Surface Scattering Coefficients

Different surfaces inside the telescope may have different reflection/scattering characteristics; for the power transfer calculations from one surface to another, each surface must be assigned the proper characteristics. Surfaces which have been treated to have a low total reflectance (such as with 3M Black Velvet or Martin-Marietta Black Anodize) may, as a fair approximation, be considered as true diffuse reflectors, with incident light being scattered uniformly over the hemisphere according to the Lambertian cosine law. The total reflectivity (integrated over the hemisphere) of 3M Black Velvet was taken as 3.0% and Martin-Marietta was 0.85%. (Note: These figures were determined from laboratory tests conducted at the U of A in the visible portion of the spectrum and might not apply for other regions of the spectrum.)

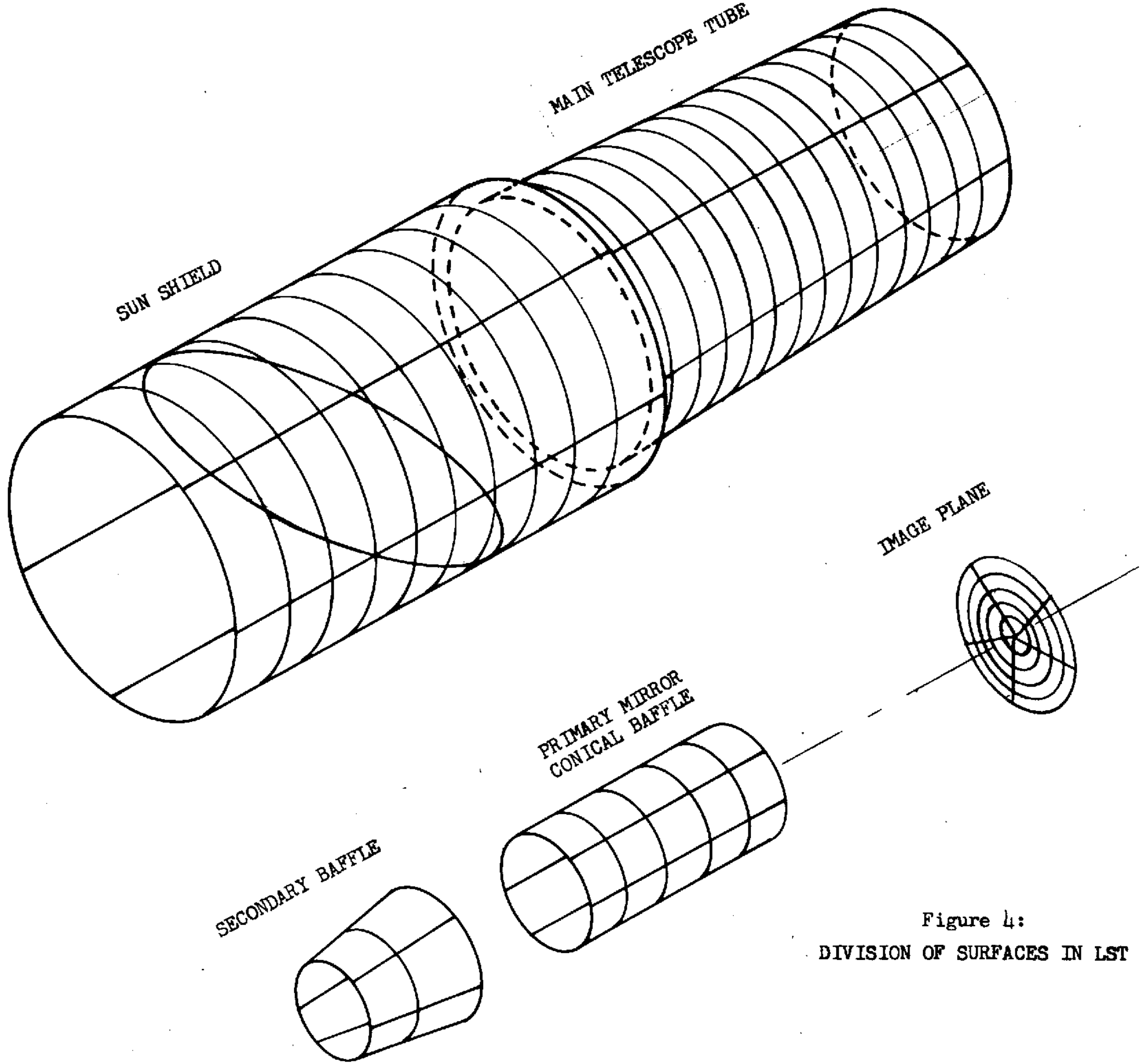


Figure 4:
DIVISION OF SURFACES IN LST

TABLE I: SCATTERING SURFACES FOR LARGE SPACE TELESCOPE

Surface No.	Surface Description	No. of Segments	No. of Annular Rings	Total No. of Incremental Areas
1	Sunshield [(1)]	5	10	50
2	Main Telescope Tube	5	14	70
3	Outside of Secondary Mirror Conical Baffle	5	2	10
4	Inside of Secondary Mirror Conical Baffle	5	2	10
5	Outside of Primary Mirror Conical Baffle	5	5	25
6	Inside of Primary Mirror Conical Baffle	5	5	25
7	Back Side of Secondary Mirror Housing	5	4	20
8	Portion of Secondary Mirror Housing that can be Seen by Image Plane	5	4	20
9	Secondary Mirror	5	8	40
10	Primary Mirror	5	10	50
11	Image Plane	5	10	50

Notes: (1) The sunshield is considered to be an extended cylinder. For the truncated sunshield, those areas which are cut away are given a reflectivity coefficient of zero, so the computer program does not consider them when computing power transfer.

The inner surface of the sunshield on both the Phase A LST and the LST with the tilted sunshield is coated with Catalac Glossy Black epoxy paint, which has a high specular reflectance (approximately 10%) but a low diffuse reflectance (0.12%); this coating may be used to advantage on surfaces where the direction of incident light may be restricted to angles such that the specular reflection is in a direction which can not add to the scattered light problem.

The optical surfaces were considered as having very high specular reflectance (100%) and a Lambertian diffuse scattering of 0.01%. It is known that this model is not correct for optical surfaces, since the reflectance is normally between 90 and 95% and the scattering near the angle of reflectance may be much higher than the scattering for angles removed from the angle of reflectance. The model for optical surfaces will be corrected as time permits, but for the present analysis the simplified model was believed to be sufficiently accurate.

Surfaces which contain baffle rings, such as the inside of the telescope tube, have a more complex model as is shown in Figure 5. The physical model is illustrated in 5(a); the reflecting surface is considered to be a smooth surface which is even with the tips of the baffle rings. However, the reflectivity characteristics of the surface is rather complex, being highly dependent on the angle of the incident light, α, on the direction to which the light is being scattered, β, and on the inclination angle of the baffle rings, γ. Figure 5(b) shows a typical characteristic for light scattered to a rearward angle of 30° as the angle of incidence is varied from near 0° to near 180°. (Note: The reflection characteristics were determined by laboratory tests on scale models of a section of the baffled surface.) Assuming that the interior baffle surfaces are coated with a low reflectance coating, the reflection characteristic remains essentially constant at a low value as the angle of incidence increases from zero to the angle of the baffle rings; the amount scattered is mostly that from the baffle edges. When the angle of incidence exceeds the angle of the baffle rings, there is a large increase in the amount of light scattered in the forward direction since the back surface of the baffle rings is then illuminated.

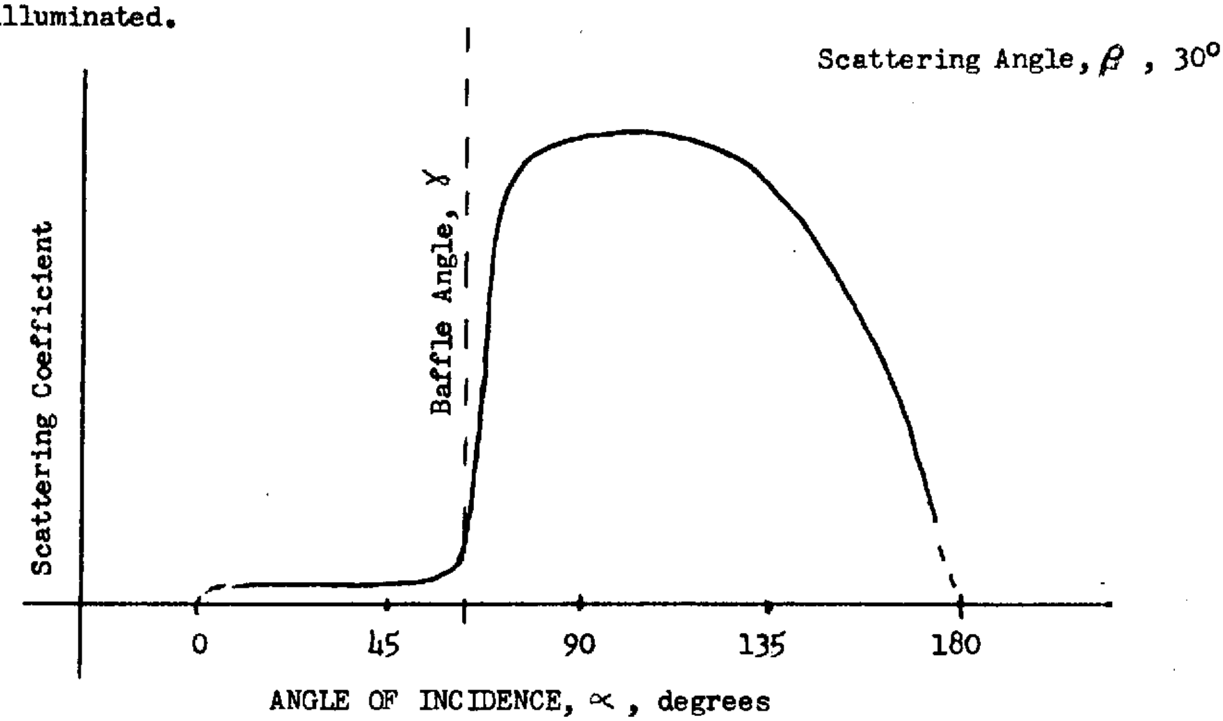


Figure 5(b): Scattering Coefficient-vs-Angle of Incidence

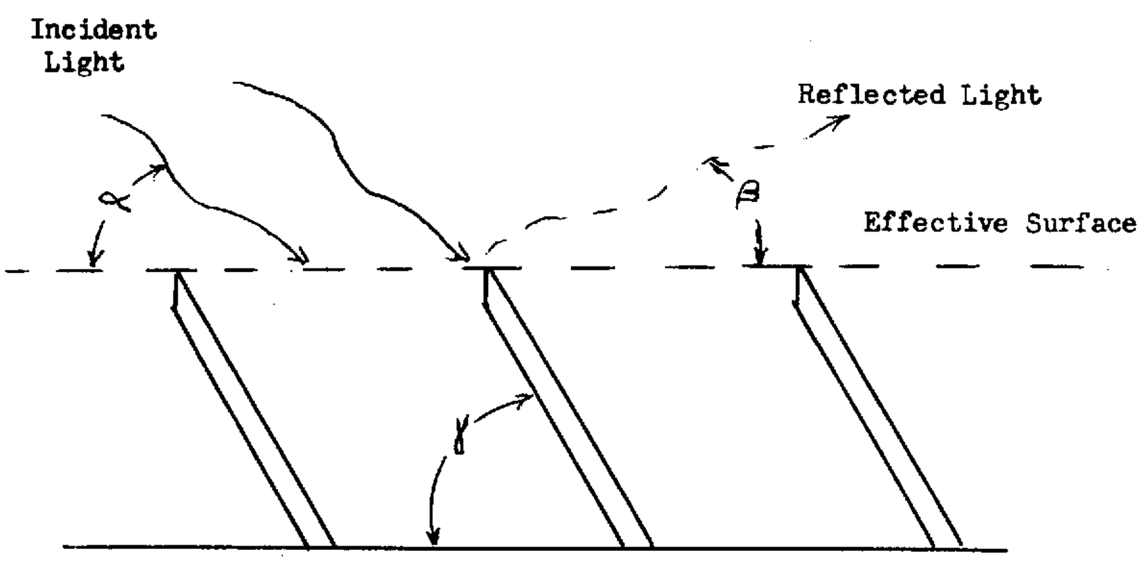


Figure 5(a): Physical Model of Surface with Baffle Rings

III. DESIGN CONFIGURATIONS ANALYZED BY THE U OF A COMPUTER PROGRAM

Three basic configurations of the LST have been analyzed by the U of A computer program to compare the effectiveness of the different design approaches in reducing unwanted scattered light at the image plane. Several variations of each design were examined, so that a total ten computer runs were made.

A. Phase A LST--Truncated Sunshield

Figure 6 is a simplified drawing of the Phase A LST which was originally presented in the U of A report "Midterm Progress Report, Stray Light Suppression Study for Large Space Telescope", Rpt. No. S 72-30, June 1, 1972, and in the Itek report "LST Phase A Study", Rpt. No. 72-8209-2, January 8, 1973. The operating restraints for the design are shown in the figure--the sun is not permitted to shine into the telescope barrel at all (limiting the closest look angle to the sun to 45°), and light from the bright earth must hit the underside of the sunshield at an angle of 90° or more, so that the specular reflection of the light is out of the tube rather than further into the tube. The underside of the sunshield is coated with a finish which has a very low coefficient of diffuse scattering (Catalac Glossy Black paint or a thin film "black mirror"). Catalac Black was used for the computer.

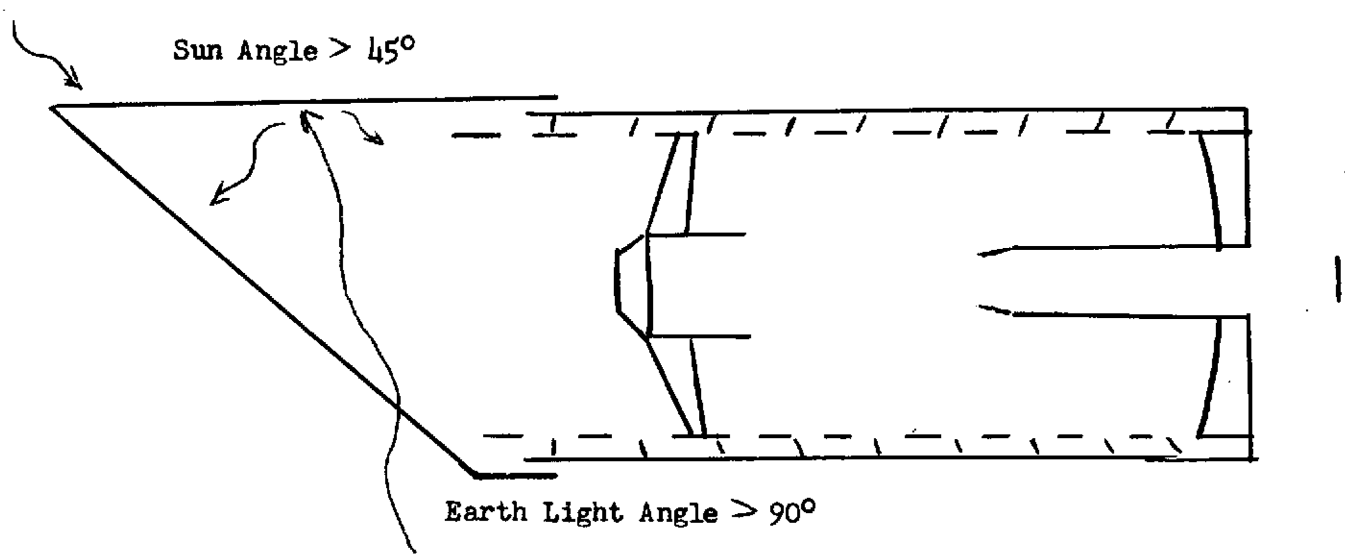


Figure 6: Phase A LST

B. Extended Cylindrical Sunshield

Figure 7 shows an LST with an extended cylindrical sunshield. If space and/or design limitations permit, it is desirable to have the sunshield diameter considerably larger than the telescope tube and to have ring baffles in the extended portion of the sunshield as well as in the main telescope tube. (Both designs have been analyzed.)

Operating constraints with this design permit both sunlight and earth light to shine into the extended portion of the sunshield, but not as far as the main telescope tube. The configuration illustrated permits operation to within 45° of both the sun and the earth. The inside surface of the sunshield is coated with Martin-Marietta Black Anodize.

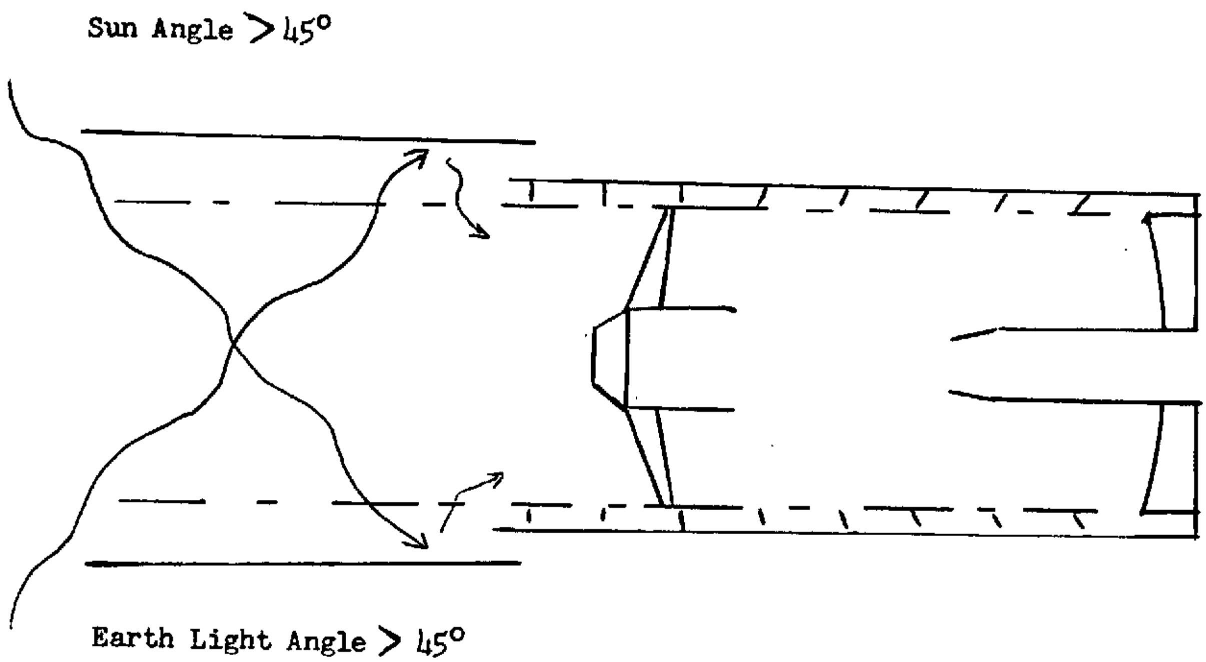


Figure 7: LST with Extended Cylindrical Sunshield

C. New U of A Proposed Design--Tilted Sunshield

Figure 8 depicts a configuration which fulfills the conditions which analysis with the computer program have shown to be desirable for achieving maximum suppression of scattered light. (See Section V for a more complete discussion of the design requirements.) A truncated sunshield is used so that operation within 45° of the sun is possible without any sunlight entering the telescope tube. However, unlike the Phase A design, the sunshield is tilted, so that none of its undersurface is "seen" by any portion of the telescope which in turn is "seen" by the image plane; as a result, only light with third-order or higher scatter can reach the image plane. (Section V will also discuss the order of scattering.)

The underside of the sunshield is again coated with a specular black coating, Catalac Glossy Black. Although the diffuse reflection characteristics of this paint are not quite as good as the "black mirror" thin film coating originally recommended, it is much more durable and several orders of magnitude less expensive.

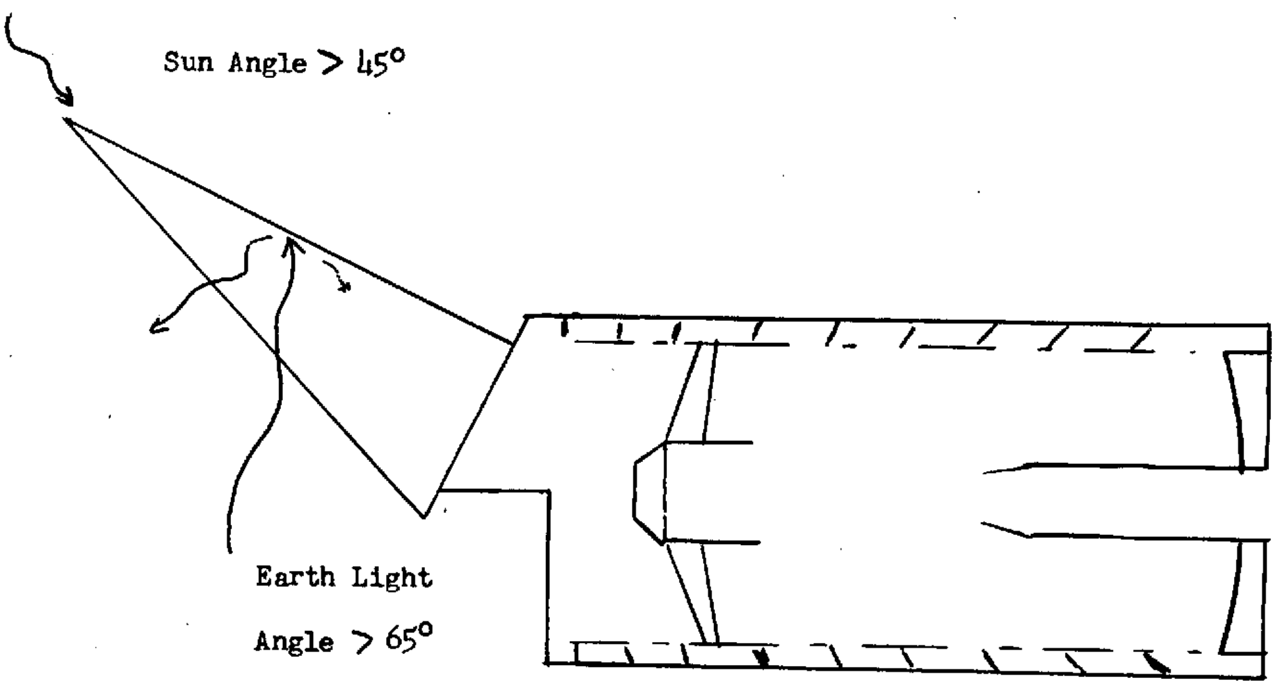


Figure 8: New U of A Proposed Design--Tilted Sunshield

IV. RESULTS OF COMPUTER ANALYSIS

A total of ten computer evaluations were made, one for the original Phase A design, three for the extended cylindrical sunshield, and six for the tilted sunshield concept. Two additional evaluations were made by extrapolating the results from these ten runs. Only one computer run was made on the Phase A design because it was apparent that that design was considerably inferior to the other two designs.

Table II is a summary of the results. The stray light levels as calculated by the computer were a factor of ten lower than those listed in the table; however, the computer program assumed that conditions were perfect, with no dirt or contamination on any of the surfaces, etc. The factor of ten was added in an attempt to compensate for actual conditions. This is at best an educated guess, and may well be changed as more information becomes available. No attempt has been made to estimate light contributions from any contamination "cloud" which may be in front of the telescope.

The dark sky has background light equivalent to approximately 1 M_v 23 star per $\widehat{sec}^2$; it is desirable to have the scattered light somewhat below this level, or perhaps the equivalent of 0.3 M_v 23 stars per $\widehat{sec}^2$. It is seen that the results for the tilted sunshield design, evaluations 7-12, are quite encouraging, and that the cylindrical sunshield with baffle rings in both the tube and sunshield (#5) is perhaps an acceptable design. The Phase A design (#1 and #2) was very poor by comparison, for reasons which became evident when the computer analysis was examined. (See Section V for a more complete discussion).

Evaluations #4 and #5 are deceptive--it would appear that adding baffle rings to the main telescope tube does little good and that the addition of baffle rings to the sunshield is very helpful. This is not the case--it is

TABLE II: RESULTS OF COMPUTER ANALYSIS OF LST DESIGNS

Evaluation No.	Design Description	Input Power On Sunshield, watts	Stray Light Reaching Image Plane, watts	Equivalent Number of M_V 23 Stars per $\widehat{sec}^2$
PHASE A LST--TRUNCATED SUNSHIELD				
1	Baffle Spacing one-half that of Phase A design	1737	$2.3(10)^{-10}$	75
2*	Same as # 1, Sun Loading	8700	$1.15(10)^{-9}$	375
LST WITH EXTENDED CYLINDRICAL SUNSHIELD				
3	No Baffle Rings on Either Sunshield or Telescope Tube (Earth @ 45°)	1039	$1.7(10)^{-9}$	560
4	Baffle Rings in Telescope Tube	1039	$7(10)^{-10}$	230
5	Baffle Rings on Both Sun-Shield and Tube Wall	1039	$3.6(10)^{-12}$	1.2
6*	Same as #5, but With Sun Light and Earth Light Both Loading Sunshield	6240	$2.2(10)^{-11}$	7.2
NEW U OF A DESIGN--TILTED SUNSHIELD				
7	Phase A Spacing on Baffle Rings (Earth @ 67°)	3243	$1.7(10)^{-12}$	0.55
8	Double the Number of Baffle Rings	3243	$7(10)^{-13}$	0.23
9	Same as #8, But Baffle Ring Edges not Considered	3243	$6.6(10)^{-13}$	0.22
10	Same as # 8, Auxiliary Slide Open (Earth @ 90°)	2116	$4(10)^{-13}$	0.13
11	Same as #10, Baffle Ring Angle 90°	2116	$4.4(10)^{-13}$	0.15
12	Same as #10, Auxiliary Slide Forward, Shading Part of Sunshield	731	$1.5(10)^{-13}$	0.05

*Not run on computer--data extrapolated from other runs.

the combination of rings on both of the surfaces which is responsible for the improvement; the addition of rings to the sunshield alone would result in poor performance.

Evaluation #8 shows the effect of doubling the number of baffle rings; although the scattered light is reduced by a factor of 2.4, the improvement might not be worth the added expense. A more desirable method of obtaining the same improvement would be to increase the tube diameter so that the baffle rings could be deeper but not increased in number.

Evaluation #9 demonstrates that the contribution from the baffle edges themselves is minimal; #11 indicates that the angled baffle rings may not be worth the additional complexity, although further analysis of this parameter should be made before reaching any decision.

V. RECOMMENDED LST DESIGN

The U of A computer program has proven to be very useful in formulating improved designs for light suppression systems; the program prints out all of the areas which are scattering light to the image plane, and the contribution of each area. It is a matter of a few minutes analysis to determine the problem areas which are causing most of the trouble and which must be improved in order to appreciably improve the system.

In order to compute the amount of light reaching the image plane, several levels of scattering must be considered. Any light reaching the image plane directly, without being scattered off another surface is direct light. (Note: For the purposes of this study, light which is seen in specular reflection off of any optical surface is considered to be seen directly, without the reflection.) Light which reaches the image plane after one scattering is first-order scatter, light which scatters twice before reaching the image plane is second-order scatter, etc. An important feature of this program is that it works through successively higher orders of scattering--that is, it computes all of the unwanted light reaching the image plane due to first-order scatter, then all that is due to second-order scatter, etc. It has been found, for all practical cases, that once there is light reaching the image plane due to any order of scattering, that the program may be stopped and the analysis considered complete, because the contribution of light from the next higher order of scattering will be at least an order of magnitude smaller. In theory, then, it is easy to improve a design--determine what surfaces are contributing low-order scattering and "eliminate" those surfaces!

A. General Guide Lines for Design

In practice, of course, it may not be easy to eliminate an offending surface. However, a set of general guide lines have been formulated which, if met, will probably result in a satisfactory stray light suppression system.

1). Do not permit the image plane to directly see the sky background.

Solution: Use primary and secondary conical baffles.

2). Do not permit the image plane to see any surface which is illuminated by singly scattered light from the sun or bright earth. Areas seen by the image plane for the 3-meter LST are:

a. Inside surfaces of the primary and secondary conical baffles.

b. Surfaces of the primary and secondary mirrors.

c. The rearmost 0.6 m of the telescope tube.

d. The secondary mirror support vanes.

It follows, therefore, that these areas must not "see" any surfaces which are directly illuminated by bright earth or sun light. The result is thus that no first-order or second-order scattered light reaches the image plane, but only third or higher orders.

Solutions: See next Section.

3). Where space permits, all interior surfaces of the telescope structure should have the effective area reduced through the use of razor-sharp baffle rings.

All surfaces should be treated with low reflectivity coatings. Note that when third-order scattering is considered, that the absorption coefficient of a light scattering surface tends to affect the final answer as a function of the cube of the characteristic.

4). Use special treatments on the critical areas seen by the image plane (those listed in 2). These treatments may include

a. Mirror surfaces should be "super smooth".

b. Special light traps, etc. for the last 0.6 m of the telescope tube and on the rear edges of the secondary mirror support vanes.

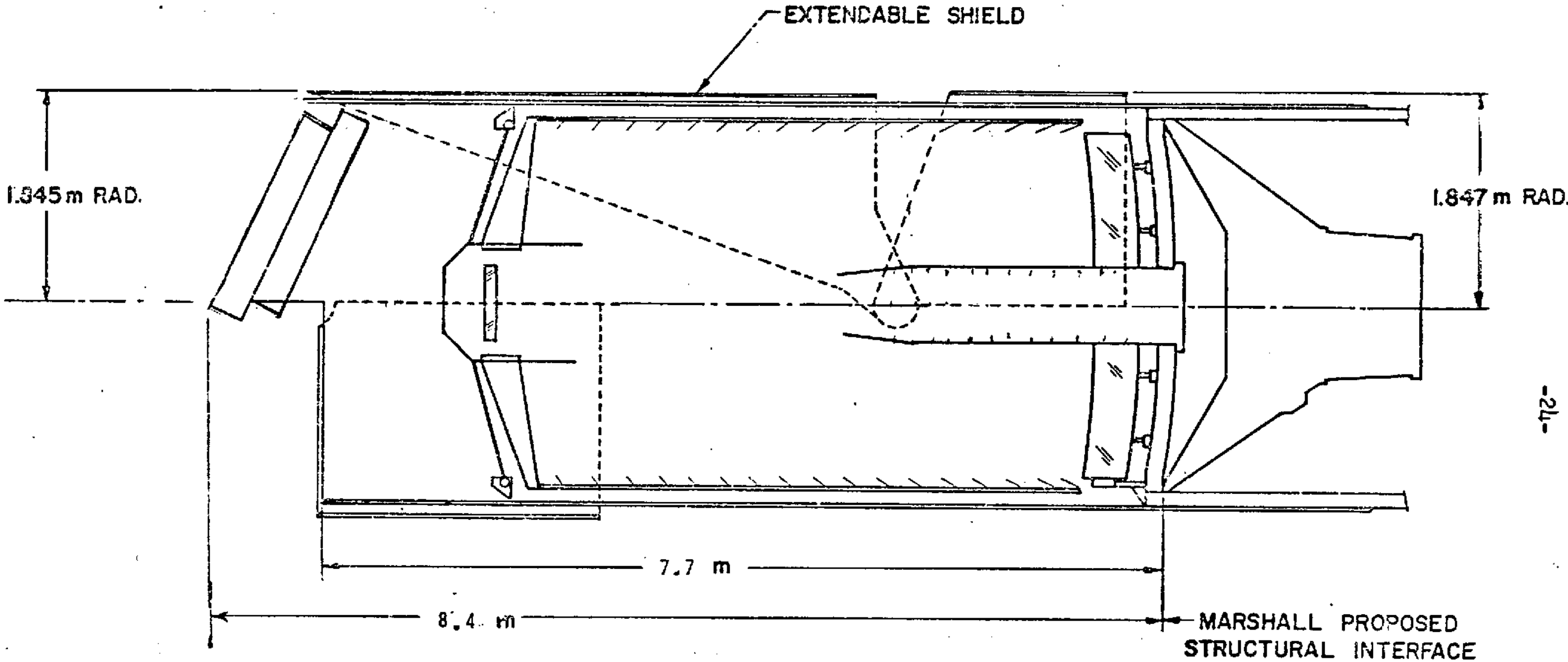
c. Use directional reflection characteristics on those areas where the direction of illumination can be controlled.

5). Reduce the propagation of scattered light down the telescope tube through the use of variable baffle spacings and angles.

B. One Design Which Meets Guide Line Requirements

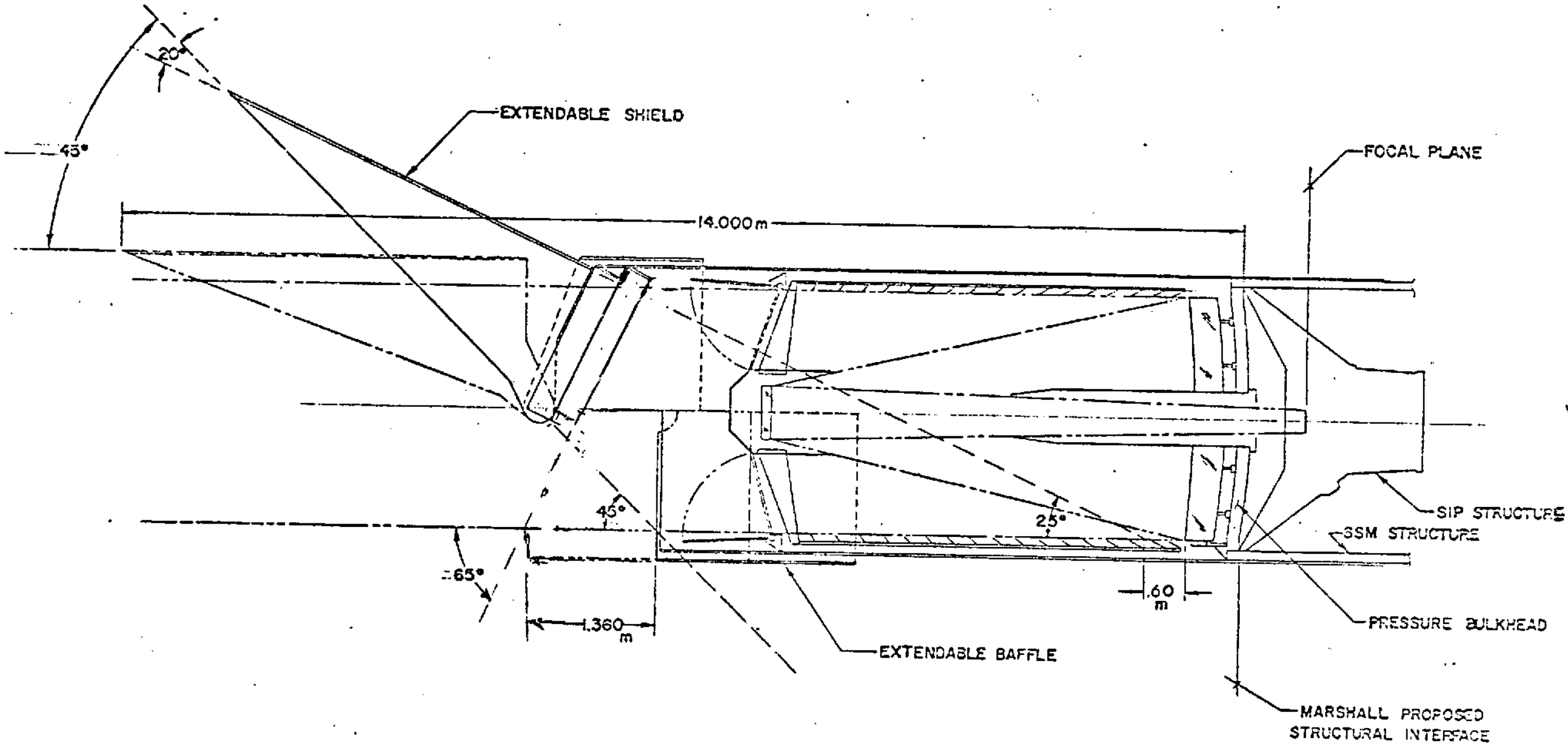
Using the computer program to assist in the design process, the U of A has evolved a configuration which meets the design guide lines of Section A, designated as the New U of A Design--Tilted Sunshield. This configuration is not intended to be the final design, but illustrates one approach which apparently reduces the scattered light to a satisfactorily low level.

The size restrictions were taken to be the same as for the Phase A design, that is, to accommodate a possible Viking shroud launch. Figure 9 shows the telescope in the launch configuration, Figure 10 the deployed configuration, and Figure 11 the top and end views. The key feature of the design is the extendable sunshield which is a conical section of half a cylinder. After reaching orbital position, the sunshield is extended and then tilted upwards (towards the sun) by an angle of 25°. No sun light or earth light is permitted to enter the telescope tube; the bright earth illuminates the underside of the sunshield, but this illuminated surface cannot be seen by any of the critical areas that in turn are seen by the image plane.



SIDE VIEW LARGE SPACE TELESCOPE--LAUNCH CONFIGURATION

Figure 9



SIDE VIEW OF LARGE SPACE TELESCOPE - SUNSHIELD DEPLOYED

Figure 10

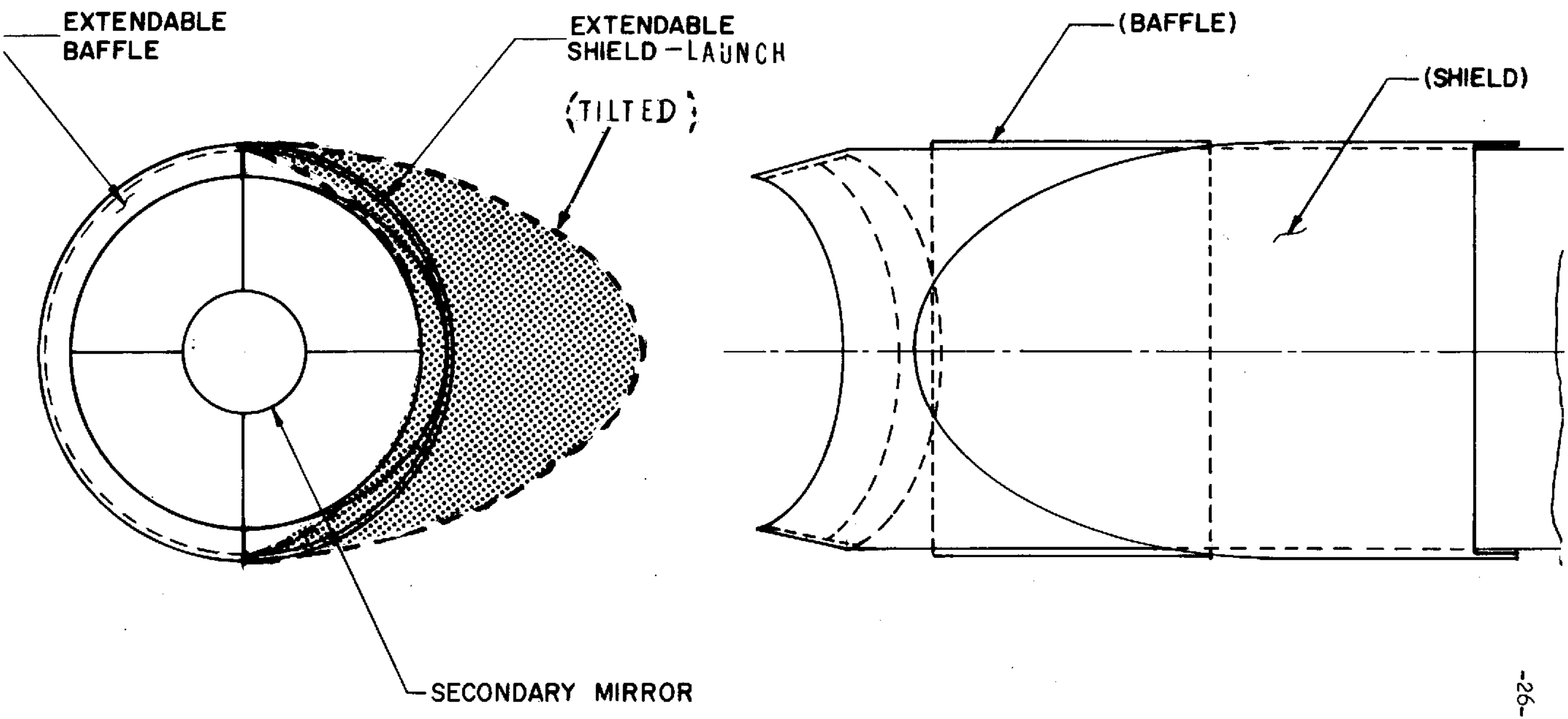
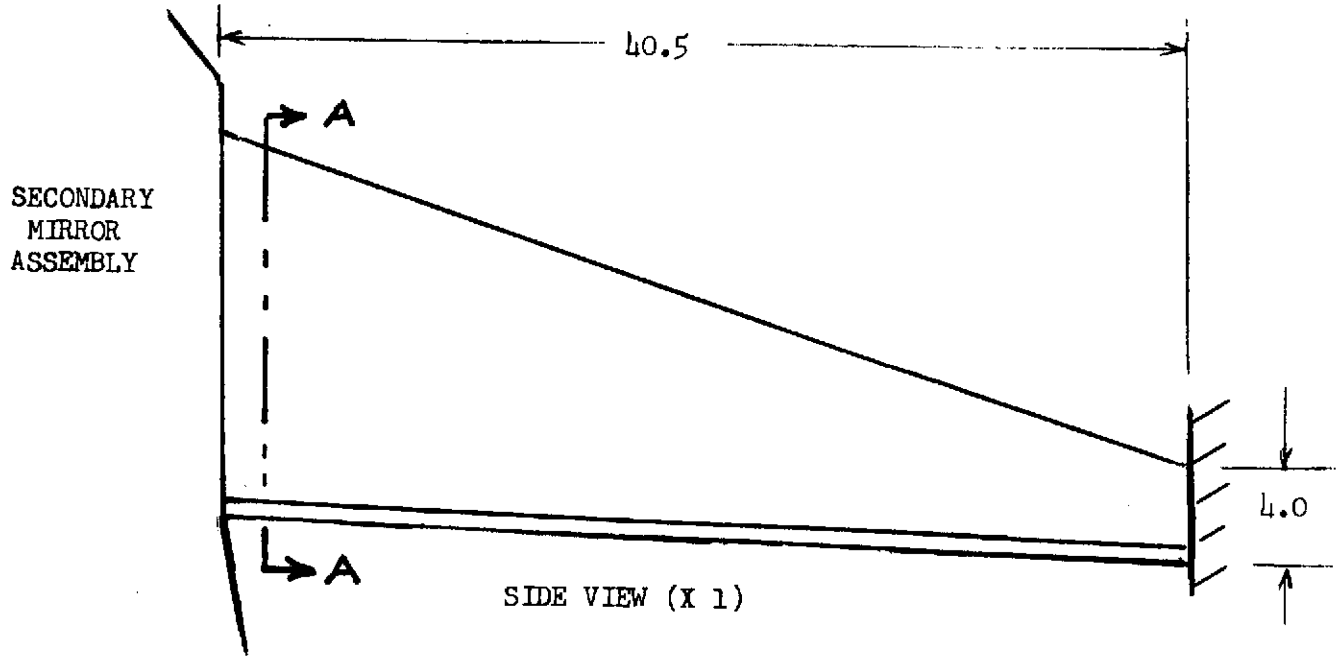


Figure 11: TOP AND END VIEWS OF LARGE SPACE TELESCOPE

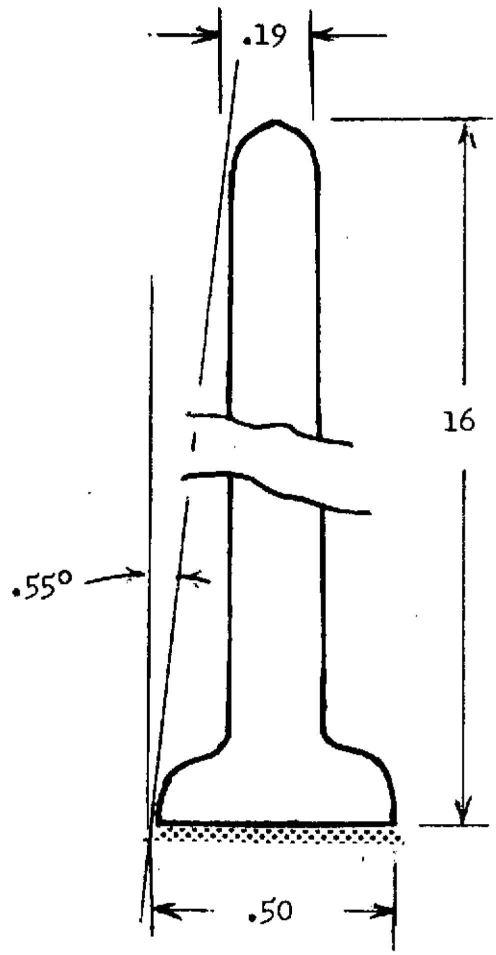
The underside of the sunshield is coated with Catalac Glossy Black paint, which has a very low diffuse reflectance coefficient (0.12%), so that little of the incident light is scattered into the telescope tube. The fact that this finish has a high specular reflection (10%) is not harmful, because the specular reflection is directed out of the telescope. This is accomplished by imposing the operating constraints shown in Figure 8; operation is permitted to within 45° of the sun or to within 65° of the bright earth. Notice that both of these limits cannot be obtained at the same time; if the sun is closer than 65° to the look angle, an auxiliary baffle slide at the bottom of the telescope is slid back so as to prevent the sunlight from striking the bottom of the tube. In this case, operation with respect to the bright earth is permitted only to within 90°.

The inside surfaces of the telescope are coated with the Martin-Marietta Black, which has a total reflection coefficient of only 0.85% (compared with 3% for 3M Black Velvet). The optical surfaces are "super smooth" to reduce the scattering (also to improve the image quality in the ultra violet).

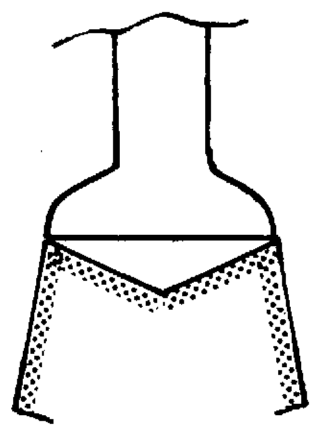
Although the illuminated sunshield does not scatter light directly to the optical surfaces or the rearmost 0.6 m of the telescope tube, it does transmit first-order scatter to the secondary mirror support vanes. Since these vanes are directly in the field of view, some provision must be made to keep this first-order light from being seen by the image plane. Figure 12 shows a possible solution to this problem--the vanes are "T" shaped, so that only the bottom edge is seen by the image plane, and this surface is not illuminated by the sunshield. However, this surface is potentially such a potent source of light to the image plane that it may be necessary to install special light traps on this lower edge; one possible treatment is illustrated in the figure.



SIDE VIEW (X 1)



SECTION A-A (X 20)



POSSIBLE EDGE TREATMENT

Figure 12

SECONDARY MIRROR SUPPORT VANE

Figure 9 showed the baffle rings in the telescope tube as having different angles of inclination and different spacing. Studies to date have indicated that there is a definite improvement in baffle performance by deviating from the "standard" 90° baffle rings with even spacing. Further computer analysis sill be required in order to determine the optimum configuration, and then a cost-effectiveness analysis will have to be made to determine if the improvement in performance is worth the added cost.

Baffle rings are badly needed on the inside of the primary conical baffle; unfortunately, there is little room for rings without increasing the obscuration.

C. Other Designs Worth Further Study

Studies to date have concentrated on LST configurations which meet the size limitations imposed on the Phase A LST and which are easy to deploy. If these size restrictions are relaxed, and/or more sophisticated deployment methods are considered, there are probably configurations which will give better performance than the new U of A design, particularly with respect to operating constraints on sun angle and earth angle. Table II on page 20 revealed that the LST with extended cylindrical sunshield is becomming effective when the sunshield diameter is made large enough so that it may include baffle rings. An extention of this approach, with even larger sunshields, might give much better performance and will be studied as time permits.

The next two figures show possible configurations. Figure 13 is an LST with a large sunshield with diffuse coating on the inside of the sunshield; baffle rings might be added to improve performance. Figure 14 shows an LST with a compound sunshield--part of the inside of the sunshield is coated with glossy black coating, the rest with a diffuse black. Sunlight or earth light which enters the sunshield has the specular component of reflection directed deeper into the sunshield where it is trapped; the diffuse component which enters the telescope tube is very small.

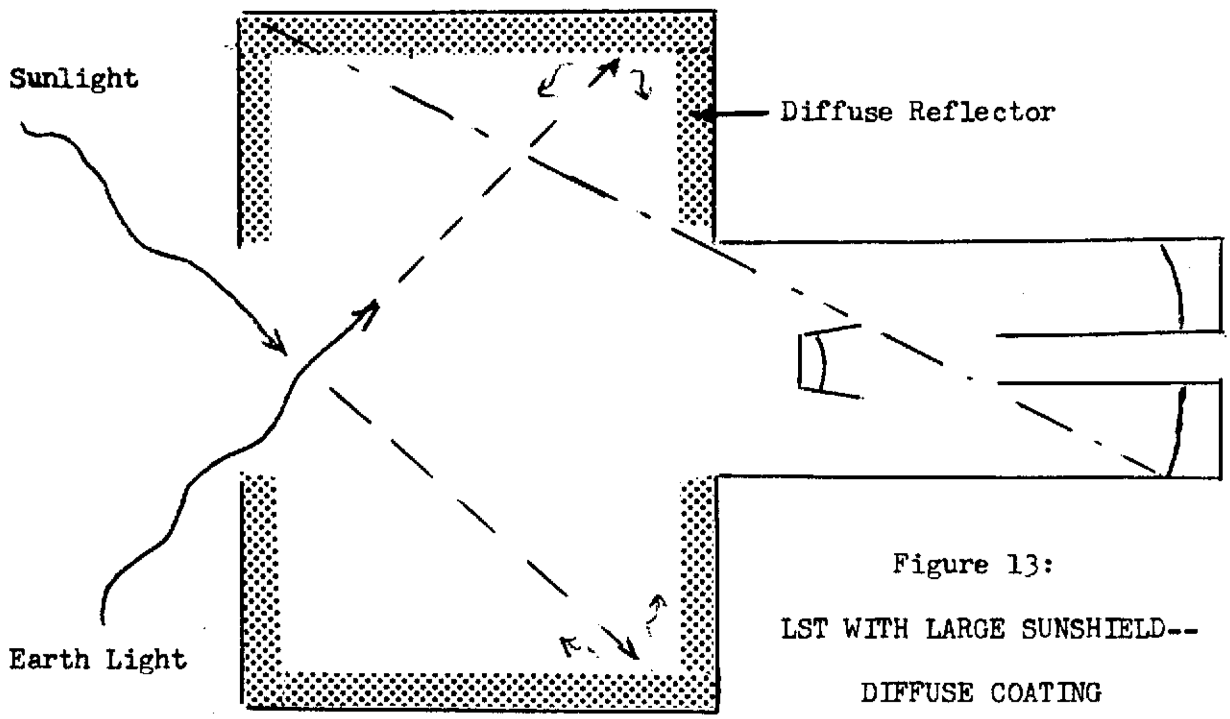


Figure 13:

LST WITH LARGE SUNSHIELD--

DIFFUSE COATING

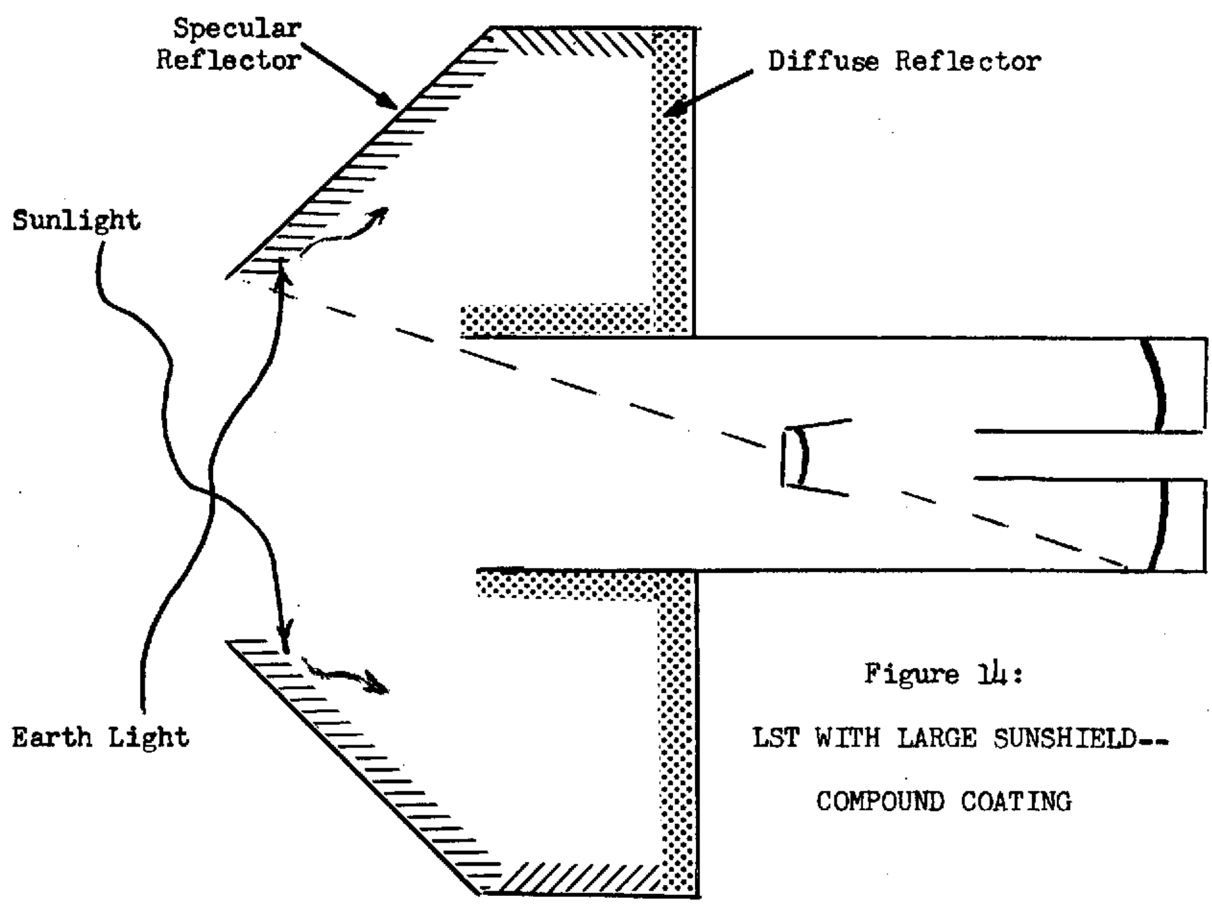


Figure 14:

LST WITH LARGE SUNSHIELD--

COMPOUND COATING

VI. CONSLUSIONS

The University of Arizona computer program for the analysis of stray light suppression systems is functioning and is giving repeatable and apparently accurate answers as to the effectiveness of various light suppression systems for the LST. As a result of ten analyses that have been made, it appears that it is feasible to obtain a light suppression system which is practical to construct and will permit operation of the LST to very faint levels (M_V 28 or 29) even when on the bright side of the earth. For this faint operation there are some operational constraints as to minimum sun angle and bright earth angle, but these constraints are no where near as severe as restricting operation to the dark side of the earth.

Some corroborating evidence as to the accuracy of the analyses made by the program is needed before complete faith can be placed on the results. It is hoped that additional evidence will be obtained by two approaches:

(1) Testing a scale model of the LST in the laboratory and comparing the test results with results predicted by the computer program.[1]

(2) Using the computer program to analyze the OAO Copernicus and comparing the results with those obtained from observation of selected objects by Copernicus while operating in orbit.

There is a need to analyze more configurations of the LST in an attempt to devise the "optimum" light suppression system and to conduct cost-effectiveness studies in order to obtain the best practical system. The computer program has proven to be very effective (and inexpensive) in making repeated runs in order to optimize a giving configuration.

Notes: 1. See U of A Report No. T 74-1, "Testing a Scale Model of the Large Space Telescope to Determine the Effectiveness of the Scattered Light Suppression System", dated March 14, 1974.